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RESEARCH ARTICLE

Determination of ATC and Shortest Path Power Flow in Deregulated Power System

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ABSTRACT: One of the major challenges in deregulated power system is determination of Available Transfer Capability on the interconnected transmission lines. It is necessary to determine and accurately gauge the transfer capability remaining in the lines for further transactions, ATC determination methodology that enables one to evaluate the realistic transmission transfer capability by accounting for all related important requirements. The assessment of ATC gives valuable information to the system operator regarding the ability of an interconnected network to reliably transfer bulk power between two nodes or between different areas of the network without causing threat to system reliability. There are several methods to find ATC in deregulated system. The proposed computation of the ATC using AC power transfer distribution factors (ACPTDFs) and to determine the shortest path for the power flow between buyer and seller which is implemented by shortest path algorithm were discussed. ATC calculation of IEEE-5 bus have been simulated by using Power world simulator and the results have been presented by considering PTDF/OTDF factor and shortest path between buyer and seller is determined by considering the line impedance as parameter simulation is carried out using MATLAB

KEYWORDS: Deregulation Power System, ATC, ACPTDF, OTDF, Shortest Path Algorithm

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1. INTRODUCTION

Deregulation of the electricity industry throughout the world aims at creating a competitive market to trade electricity, which generates a host of new technical challenges to market participants and power system researchers. For both planning and operation of the bulk power electricity market, accurate identification of transfer capability provides vital information. It is important for power system planners to know the system capacity and stability. It is also important for system operators to see that transfers are not to exceed the calculated transfer capability[1][2]. Estimates of transfer capabilities must be updated regularly as to avoid the combined effect of power transfers from causing an undue risk of system overloads, equipment damage, or blackouts. For transmission systems, it requires non-discriminatory open access to transmission resources [3]. To improve the system reliability and services support and full utilization of transmission assets, calculation of ATC is needed. ATC from a bus/zone '*m*' to another bus/zone '*n*' can be found using the full AC load flow by varying the amount of transaction until one or more line flows in the transmission system considered or a bus voltage at some bus reaches the limiting value. Mathematically, ATC equals the total transfer capability (TTC) less the transmission reliability margin (TRM) less the capacity benefit margin (CBM) and existing transmission commitments (ETC). In deregulated scenario there may be more than one injection points anyone can be seller and buyer. To transfer the bulk power based on market demands, ATC is calculated hourly, daily or monthly and it is displayed on a website named Open Access Simultaneous Information System (OASIS). It is mandatory to check ATC before carrying out any commercial power transaction. In case, the amount of power to be transacted is more than ATC, the transaction is denied or it is limited to ATC of the network. It is necessary to determine the shortest path for the power flow between seller and buyer to transmit the power through low impedance path so that to reduce the line losses and power wheeling. To determine the shortest route among the available paths graph theory techniques has to be implemented on the

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network [4].

The objectives of this research work creating a competitive market to trade electricity. In deregulated power system transmission networks plays vital role in competitive electricity markets, because individual power producers(IPP) will compete with each other to provide the best possible service at lowest cost and high power quality in order to attract and retain customers . For better transmission services support and full utilization of transmission assets, one of the major challenges is to accurately gauge the transfer capability remaining in the system for further transactions, which is termed the available transfer capability (ATC). The transaction between seller and buyer, to transfer power between should through the optimal path/ shortest path. Therefore graph theory algorithms are applied in the deregulated system to determine the shortest path between seller and buyer.

2. METHODOLOGY

In literature, some common method have been reported to find ATC namely, continuation power flow (CPF), DC Power transfer distribution factor and AC-Power transfer distribution factor (AC-PTDF). In this paper AC-PTDF method was presented on standard IEEE bus systems under deregulated scenario by consider linear sensitivity of system and uses AC power flow to calculate ATC by taking line outage distribution factor and power transfer distribution factor[4,5].

2.1 PTDF Calculation

PTDFs determine the linear impact of a transfer (or changes in power injection) on the elements of the power system. These values provide a liberalized approximation of how the flow on the transmission lines and interfaces change in response to transactions between the seller and buyer. For a single area ATC, the transaction will be between the seller bus and buyer bus present in the area for a multi-area ATC, the transaction will be between two areas or two zones. At the base case PTDF is equals to OTDF (outage distribution factor) or line outage distribution factor (LODF) [5].

2.2 ACPTDF Formulation

The ACPTDFs proposed for the calculation of ATC were used to find various transmission system quantities for a change in MW transaction at different operating conditions. Consider a bilateral transaction between a seller bus m and buyer bus n. Line l carries the part of the transacted power and is connected between buses i and j . For a change in real power of X to Y in Mega Watt when the transaction b the between i and j.

PTDF is a factor which represents the percentage of change in power flow through network branch (i-j) due to the existence of a new transaction in the system (from bus X to bus Y).

$$\mathrm{PTDF} = \frac{\begin{array}{c}(\text{change in power flow through netwrok branch } \mathrm{i} - \mathrm{j} \\ \text{due to the transaction form X to Y})\end{array}}{(\text{Power transction from X to Y})}$$

It provides Incremental change of active power flow on transmission lines caused by an incremental change of the injection at some node in the network. These factors depends on the choice of balance nodes, topology and network parameters, but they are independent of the injection and power flow through system. Distribution factor for the line on which the active power is changed by ΔP due to the change of injection (production/consumption) at node.

The power trasfer limit one the lines depends on the PTDF value as PTDF is positive, so look for the element overload in the positive direction. If PTDF value is very small which means that the transfer has a very small impact on the limiting element. If PTDF is negative, so look for the element overload in the negative direction. The transfer limit is inversely proportional to the PTDF and ATC is the minimum of transfer constraint. Hence line having highest PTDF is the limiting factor for particular transaction but every time this is not true because limiting factor also depend on system topology, thermal constraint and on percentage loading of the line[6].

$$\mathrm{TM} = \frac{\text{Limit M} - \text{MW flow}}{\mathrm{PTDF}} \qquad ; \mathrm{PTDF} > 0 - - - - (1)$$

$$\mathrm{PTDF} = 0 - - - - - (2)$$

$$\mathrm{TM} = \frac{-\text{Limit M} - \text{MW flow}}{\mathrm{PTDF}} \qquad ; \mathrm{PT} < 0 - - - - (3)$$

2. RESULTS AND DISCUSSION

ATC is calculated by considering the ACPTDF

3.1 Case study

IEEE-5 bus system is considered for the case study has 2 generators. Bus 1 is slack, bus 3 as generator bus. Whereas bus 2,4,5, are the load buses. The bus data and line data of the system are shown in table 1 and 2 respectively.

Table1. Line data of IEEE-5 bus system

No. of lines	Line between buses	Impedance of line	Maximum capacity of line
1	1-2	0.0245+j0.0540	100 MVA
2	1-4	0.0245+j0.0540	100 MVA
3	1-5	0.0245+j0.0540	100 MVA
4	2-3	0.0245+j0.0540	100 MVA
5	3-5	0.0245+j0.0540	100 MVA
6	4-5	0.0245+j0.0540	100 MVA

Table2. Generator and Load details of IEEE-5 bus system

Buses	Generator		Load	
	MW	MVAR	MW	MVAR
1 (slack bus)	100	0	---	--
2	--	---	10	5
3	100	0	100	50
4	--	---	50	20
5	--	--	100	50

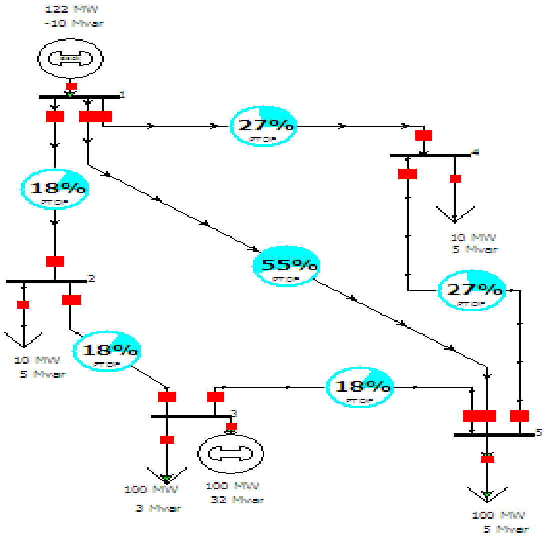
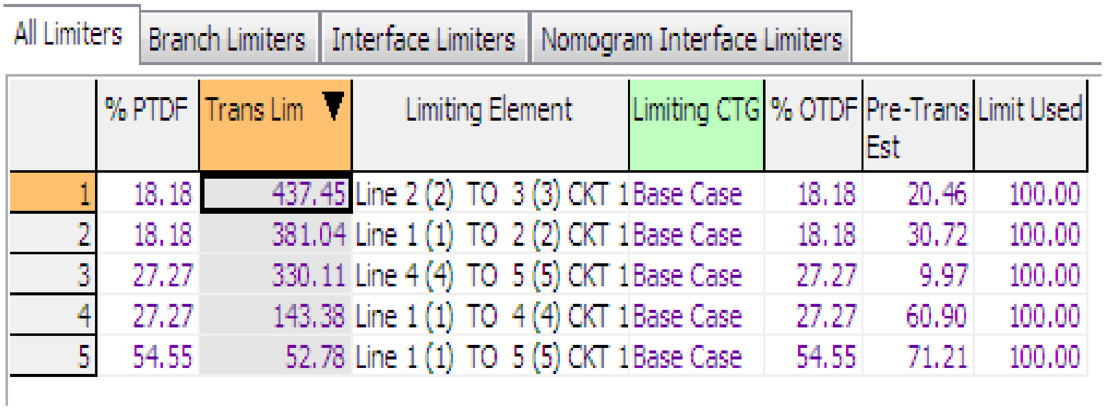


Fig.1.Normal load flow with transaction between bus1 as seller bus 5 as buyer

Table 3. Normal transction between bus1 & 5 in the netwrok with normal PTDF/OTDF values



	% PTDF	Trans Lim	Limiting Element	Limiting CTG	% OTDF	Pre-Trans Est	Limit Used
1	18.18	437.45	Line 2 (2) TO 3 (3) CKT 1	Base Case	18.18	20.46	100.00
2	18.18	381.04	Line 1 (1) TO 2 (2) CKT 1	Base Case	18.18	30.72	100.00
3	27.27	330.11	Line 4 (4) TO 5 (5) CKT 1	Base Case	27.27	9.97	100.00
4	27.27	143.38	Line 1 (1) TO 4 (4) CKT 1	Base Case	27.27	60.90	100.00
5	54.55	52.78	Line 1 (1) TO 5 (5) CKT 1	Base Case	54.55	71.21	100.00

PTDF values of the transmission system indirectly represent the current load which is being carried by the element and ultimately help to find out the Available Transfer Capacity (ATC). The same is very useful for the power trading between the seller and buyer corporations as well as for the open market transactions. A simulated sample system as shown in Figure 1 is taken for the case study. The details of the system are shown in Table 3.during normal load flow in the system. Among the available many power system simulators, Power world simulator is used to study the system behaviour. The basic simulation without any change in the load and outage of lines was done and PTDF values are displayed on the single line diagram (SLD). The sample system posses good PTDFs and have good margin to load further. This opportunity of loading further emphasises the calculation of available transfer capacity (ATC) of the system and is witnessed with Table 1. This ATC of the system indicate the remaining capacity and probe further/ future trading opportunity in the open electricity market

Further the another case study as shown in Figure 2 with line 1-5 outage and impact of the same on the system and PTDFs to evaluate ATC is simulated and analysis is presented in Table 4. The system found still closed and complete without any cascaded effects and stable. The PTDFs after the simulation again proved to be good for the case taken. The transfer capacity of each line found shifted towards its full capacity and further outages may cause break down. This information of the transfer system is very useful for the next transactions awaited from the seller and buyers view point as well as to maximize the performance of entire system in venture.

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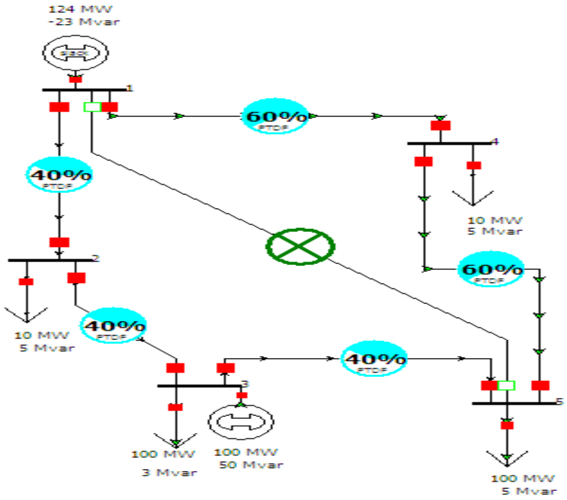

Fig.2.Line out between bus 1 and bus 5 transaction between bus1 as seller bus5 as buyer

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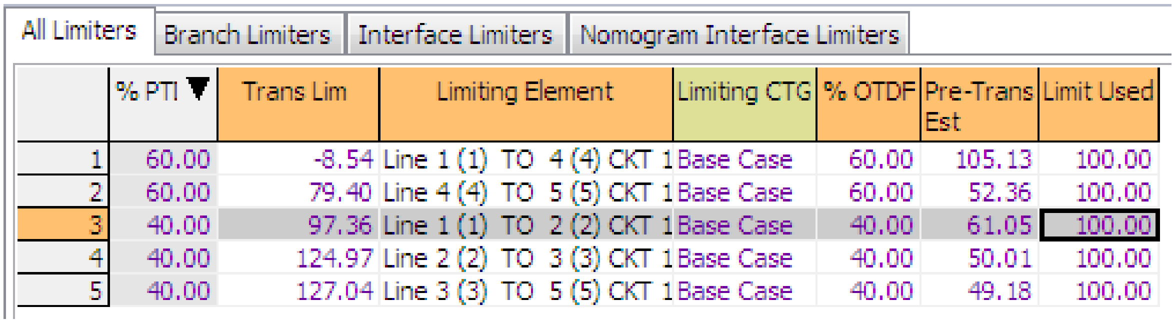
Table 4. Line out between bus 1 and bus 5 with PTDF/OTDF values with transction between 1 & 5



	% PTI	Trans Lim	Limiting Element	Limiting CTG	% OTDF	Pre-Trans Est	Limit Used
1	60.00	-8.54	Line 1 (1) TO 4 (4) CKT 1	Base Case	60.00	105.13	100.00
2	60.00	79.40	Line 4 (4) TO 5 (5) CKT 1	Base Case	60.00	52.36	100.00
3	40.00	97.36	Line 1 (1) TO 2 (2) CKT 1	Base Case	40.00	61.05	100.00
4	40.00	124.97	Line 2 (2) TO 3 (3) CKT 1	Base Case	40.00	50.01	100.00
5	40.00	127.04	Line 3 (3) TO 5 (5) CKT 1	Base Case	40.00	49.18	100.00

Another analysis from the view point of seller (Bus 1) and the buyer (Bus 5) with line 1-2 outage was simulated as in Figure 3 to confirm the consistency of the system behaviour and PTDFs. The details are presented in Table 5. The adequate generation and delivery to the buyer is matched without having any line overloading and keeping good transfer capacity margin. This evidences the ATC of the system to participate further in trading by taking the advantages of systems ATC with the PTDFs of all lines of the system in proper order.

The ATC of the system duly represents the further participation ability in power market for trading among the group of seller and buyers. It also indicates the future probable planning for the transmission network to keep security and reliability as pronounced.A continued study of the system with insertion of generator (DG) at certain bus like bus 4 has pronounced effect of keeping good transfer capacity of the system with outage of line 1-3 as shown in Figure 4. The increased loading at bus 3 and added generator at bus 4 again proved to be best without causing the violation of PTDFs. But the reverse flow between bus 3 and 5 was specially observed. The details are presented in Table 4 and 5

A comparative study of PTDF of all the lines for the specific cases is represented in Table 6. The normal load flow without any outages in the system is put in column 1 with relevant PTDFs. Column 2 shows such an analysis with outage of line 1-2 and all PTDFs. The systems ATC through PTDF values is still good to carry additional load. Column 3 represents the PTDFs with outage of line 1-5 and impact on PTDFs of other lines. The study shows the crowding on few lines of the system and meeting the transactions.

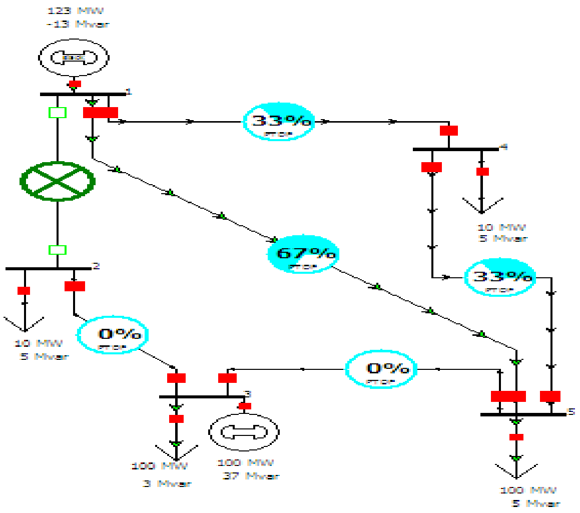
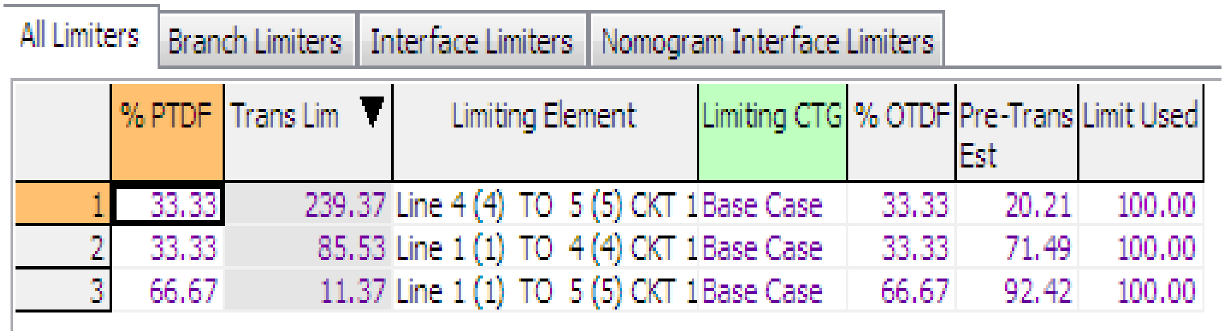


Fig.3.line out between bus 1 and bus 2 transaction between bus1 as seller bus5 as buyer

Table 5. Line out between bus 1 and bus 2 with PTDF/OTDF values with transction bwetween 1 & 5



	% PTDF	Trans Lim	Limiting Element	Limiting CTG	% OTDF	Pre-Trans Est	Limit Used
1	33.33	239.37	Line 4 (4) TO 5 (5) CKT 1	Base Case	33.33	20.21	100.00
2	33.33	85.53	Line 1 (1) TO 4 (4) CKT 1	Base Case	33.33	71.49	100.00
3	66.67	11.37	Line 1 (1) TO 5 (5) CKT 1	Base Case	66.67	92.42	100.00

Table 6. PTDF values with line out between 1-2 and 1-5

Lines	Normal load flow % PTDF	%PTDF values with line1-2 out	%PTDF values with line 1-5 out
1-2	18%	**OUT**	40%
1-4	27%	33%	60%
1-5	55%	67%	**OUT**
2-3	18%	0%	40%
3-5	18%	0%	40%
4-5	27%	33%	60%

1.2 Effect of Injection of DG on line PTDF values and ATC

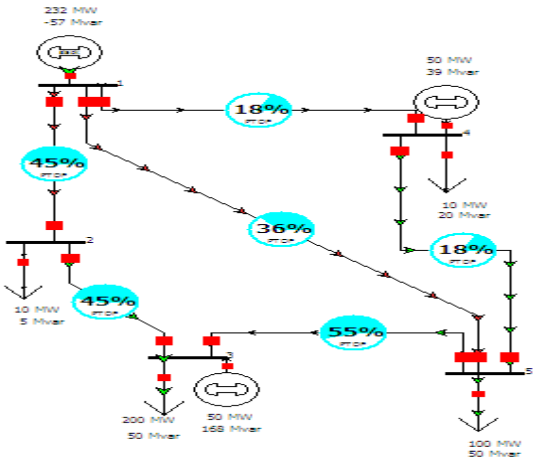
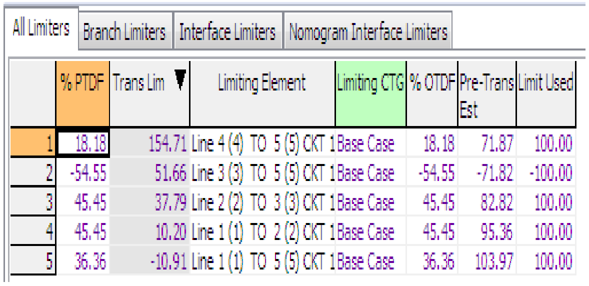


Fig.4.Insertion of DG at bus 4 transaction between bus 4 as seller bus 3 as buyer

With the increase in the demand at bus 3(buyer) DG was injected in the bus 4 (seller). Transaction between bus 4 and bus 3 changes the PDTF values. After the injection of DG ATC available is depends on PTDF of that particular line. The values of new PTDF after injection are shown in Table.7.

Table 7. Insertion of DG at bus 4 with PTDF/OTDF values with transction bwetween 4 to 3



	% PTDF	Trans Lim	Limiting Element	Limiting CTG	% OTDF	Pre-Trans Est	Limit Used
1	18.18	154.71	Line 4 (4) TO 5 (5) CKT 1	Base Case	18.18	71.87	100.00
2	-54.55	51.66	Line 3 (3) TO 5 (5) CKT 1	Base Case	-54.55	-71.82	-100.00
3	45.45	37.79	Line 2 (2) TO 3 (3) CKT 1	Base Case	45.45	82.82	100.00
4	45.45	10.20	Line 1 (1) TO 2 (2) CKT 1	Base Case	45.45	95.36	100.00
5	36.36	-10.91	Line 1 (1) TO 5 (5) CKT 1	Base Case	36.36	103.97	100.00

Table. 8 PTDF values with insertion of DG at bus 4 & increases in demand at bus 3 transactions 4-3

Lines	Normal load flow with % PTDF	With DG insertion in bus 4 %PTDF
1-2	18 %	45%
1-4	27%	18%
1-5	55%	36%
2-3	18%	45%
3-5	18%	-55%
4-5	27%	18%

A comparative study of PTDF of all the lines for the injection of DG cases is represented in Table 8. The normal load flow without any injection in the system is put in column 1 with relevant PTDFs. Column 2 shows such an analysis with injection of DG in bus 4 and transaction between 4-3 with new PTDFs values. The study shows the over loading on few lines of the system and meeting the transactions.

3.3 Determination of shortest path in system for power flow

With the IEEE- 5 bus system same line data the shortest path of power flow in deregulated power system between the seller and buyer is determined by applications of the graph theory on the power networks. By considering the previous loads flow the shortest path simulation using graph theory actual power flow in the lines are co-related. The results are found are very accurately which is having minimum impedance path that line is overloaded up to their maximum capacity compare to other line which are available between the same seller and buyer[6]. Simulation results are shown in the Fig.5 with power flow in lines using Power world simulator and Fig.6 shortest path power flow in lines using MATLAB this will provide the parallel proof for the case studies under deregulated scenario.

1st shortest path between seller and buyer

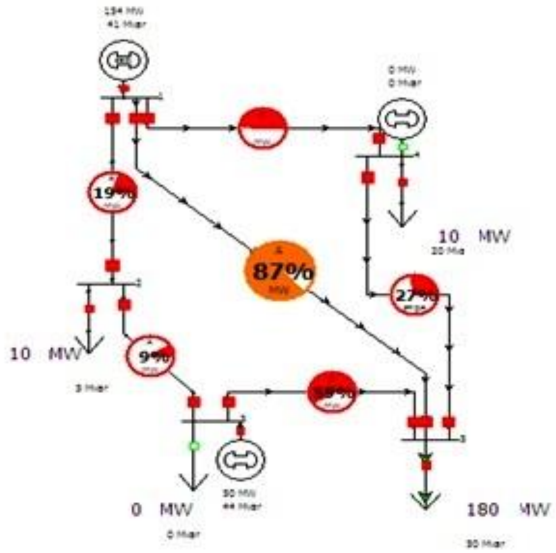


Fig.5 power flow between bus 1-5

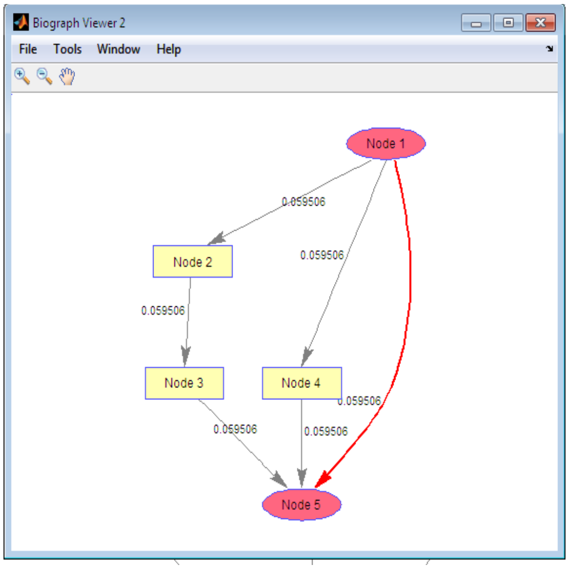


Fig. 6 shortest path of power flow between 1-5

2nd shortest path, when 1st path under maintenance or line outages

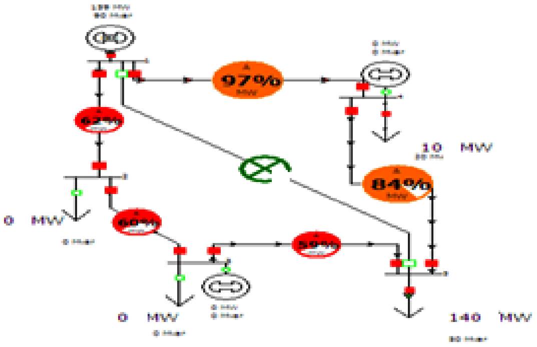


Fig.7 2nd path power flow between bus 1- 5 When 1-5 line out

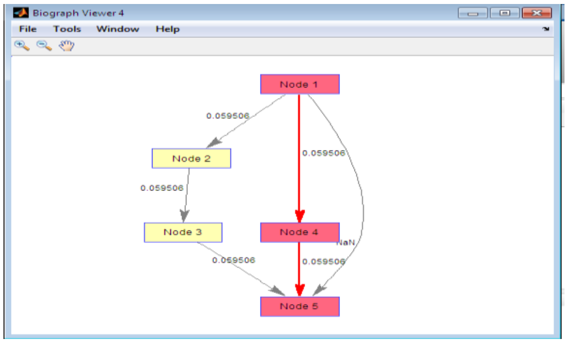


Fig. 8. 2nd shortest path of power flow between 1-5 when 1-5 line out

3. CONCLUSION

The proposed method of ATC calculation and determination of shortest path power flow in deregulated power system by considering ACPTDF and Shortest path algorithm are implemented on IEEE 5bus system. Seller and buyer concept of deregulated power systems are demonstrated using power world simulator and MATLAB software. For available transfer capacity of interconnected systems results are shown on different line outage conditions with different PTDF/OTDF values. The transaction between seller and buyer are done by looking at the ATC of the lines. The parallel proof of power flow through shortest impedance path is given by the shortest path (Dijkstra's) algorithm Power flow paths. This method is implemented on any complex networks in deregulated power system.

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